

## Performance Investigation of Coaxial Cable with Transmission Line Parameters Based on Lossy Dielectric Medium

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### Article Info

#### Article history:

Received Nov 14, 2017

Revised Apr 17, 2018

Accepted Apr 21, 2018

#### Keywords:

Coaxial Cable  
Dielectrics  
Medium  
Parameter

### ABSTRACT

This paper presents the analysis of high performance for coaxial cable with transmission line parameters. The modeling for performance of coaxial cable contains many parameters, in this paper will discuss the more effective parameter is the type of dielectric mediums. This analysis of the performance related to dielectric mediums with respect to dielectric losses and its effect upon cable properties, dielectrics versus characteristic impedance, and the attenuation in the coaxial line for different dielectrics. The analysis depends on a simple mathematical model for coaxial cables to test the influence of the insulators (Dielectrics) performance.

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## 1. INTRODUCTION

### 1.1. Background

Coaxial cable has an inner conduct or surrounded by a tubular insulating layer, surrounded by a tubular conducting shield. Many coaxial cables also have an insulating outer sheath or jacket. The term coaxial comes from the inner conductor and the outer shield sharing a geometric axis as shown in Figure 1.

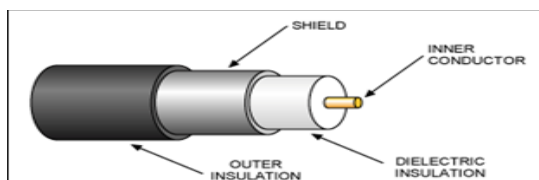


Figure 1. The cross section of coaxial cable [1]

Coaxial cable virtually keeps all the electromagnetic wave to the area inside it. Due to the mechanical properties, the coaxial cable can be bent or twisted; also it can be strapped to conductive supports without inducing unwanted currents in the cable. In frequency radiation applications up to a few GHz, the wave propagation in the transverse electric and magnetic mode only, that means the electric and magnetic

fields are both perpendicular to the focal point of propagation. Yet, at frequencies for which the wavelength (in the dielectric) is significantly shorter than the circumference of the transmission line transverse electric and transverse magnetic waveguide modes can also spread [2].

Coaxial cable conducts electrical signal using an inner conductor normally a solid copper, stranded copper, surrounded by an insulating layer (dielectric) [3] and all enclosed by a shield. The cable is protected by an outer insulating jacket. The electromagnetic waves cannot propagate through coaxial cable before they are either sucked or reflected because of the effect of the Dielectric Materials. The speed of electromagnetic waves propagating through a dielectric medium is given by:

$$V = \left( \frac{c}{\mu_r \epsilon_r} \right)^{1/2} \quad (1)$$

Where  $c = 3 * 10^8$  m/s:-the velocity of light in a vacuum,  $\mu_r$  Magnetic relative permeability of dielectric medium and  $\epsilon_r$  Dielectric relative permittivity of the dielectric [3].

## 1.2. Problem of statement

The dielectric loss due to the electric absorbing energy as it is polarized to each direction but here the major problem is losses arising from coaxial cable. Therefore, signal lost as dielectric loss is dissipated as heat and it increases with frequency. So, to improve the performance of the coaxial cable transmission line, using decreasing the shunt conductance with increasing the frequency.

## 2. MODEL OF COAXIAL CABLE

Generally, like any transmission line, the coaxial cable has these four parameters; capacitance, resistance, conductance and inductance. The model of a coaxial cable shown in Figure 2.

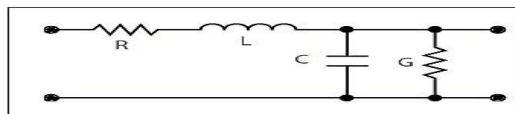


Figure 2. The electrical model of coaxial transmission line

Coaxial cables from the transmission line perspective [1] can have a valuable electrical influence on a test setup. Coaxial cables are considered as lossy elements, and assigned a lumped capacitance and/or inductance, although the electrical effects of a coaxial cable can be much more complex than a single capacitance value.

In this research, the examination of how the electrical performance of a coaxial cable has made, notably loss and distributed capacitance/inductance can affect the integrity of a signal and the differences of dielectrics [3] can change those values and finally the performance of the cable [4]. The coaxial cable circuit contains:

- a) Shunt capacitance: it is the capability of the coaxial to carry a charge. It is measured per unit length (Farad per meter) [7].

$$C = \frac{2\pi\epsilon}{\ln\left(\frac{D}{d}\right)} \quad (2)$$

- b) Series resistance: The resistance per unit length is just the resistance of the inner conductor and the shield at low frequencies. At higher frequencies, skin effect increases the effective resistance by confining the conduction to a thin layer of each conductor. To calculate this resistance it is given by:

$$R = \left( \frac{1}{2\pi} \right) * \left( \left( \frac{1}{d} \right) + \left( \frac{1}{D} \right) \right) * \left( \frac{\pi f \mu}{\sigma} \right)^{0.5} \text{ or } \sqrt{\frac{L}{C}} \quad (3)$$

- c) Shunt conductance: Generally in coaxial cables, the shunt conductance is very small because dielectrics with good properties are used (low dielectric constant). At high frequencies, a dielectric can have a significant resistive loss.

$$G = \frac{2\pi\sigma}{\ln\left(\frac{D}{d}\right)} \quad (4)$$

- d) Series inductance: to represent or simulate the magnetic field around the wires, self-inductance is represented by a series inductor is given by:

$$L = \left(\frac{\mu}{2\pi}\right) * \ln\left(\frac{D}{d}\right) \quad (5)$$

- e) Characteristic impedance: This is the total opposition or resistance to the flow of electrical energy within the cable. It is a complex value defined by the cable's resistance, capacitance, inductance, and conductance, and is the equivalent value of these items combined.

$$\frac{V(0)}{I(0)} = \frac{V_o^+ + V_o^-}{V_o^+ - V_o^-} Z_o, Z_o = \frac{V_o^+}{I_o^+} = \frac{V_o^-}{I_o^-} = \left(\frac{R + j\omega L}{\gamma}\right) = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

$$z_o = R_o + jx_o = \sqrt{\frac{L}{C}} \Rightarrow Z = ((R + jL)/((G + jC)) )^{0.5} \quad (6)$$

Where, d: Outside diameter of inner conductor, D: Inside diameter of the shield  $\mu$ : Magnetic permeability of dielectric medium,  $\epsilon$ : Dielectric permittivity of the dielectric medium and  $\sigma$ : Conductivity of the inner conductor.

### 3. RESULTS AND DISCUSSION

#### 3.1. Evolution of dielectrics with Characteristic Impedance

The equality of the coaxial cable directly depends upon the characteristic impedance. The main consideration is this impedance value should match both at the transmitting and receiving end of the transmission line.

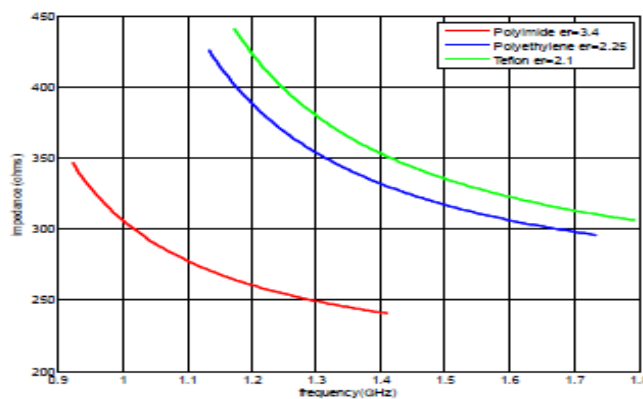


Figure 3. Shows the impedance characteristic gets less with the frequency increases

#### 3.2. Evolution of dielectrics with attenuation

The coaxial cable has a solid copper inner conductor of radius  $a = 1\text{mm}$  and a copper outer conductor of inner radius  $b$ . The outer conductor is much thicker than a skin depth. The dielectrics have different  $\epsilon_r$  [5] and the frequency 1 GHz. Letting the ratio outer to the inner diameter ( $b/a$ ) vary from 1.5 to 10, generate a plot of the attenuation (in dB/m) versus the line impedance.

$$\alpha^2 = \frac{\omega^2 \mu \epsilon}{2} \left[ \sqrt{1 + \frac{\sigma^2}{\omega^2 \epsilon^2}} - 1 \right] \Rightarrow \alpha = \omega \sqrt{\frac{\mu \epsilon}{2} \left[ \sqrt{1 + \frac{\sigma^2}{\omega^2 \epsilon^2}} - 1 \right]} \text{ NP/m} \quad (8)$$

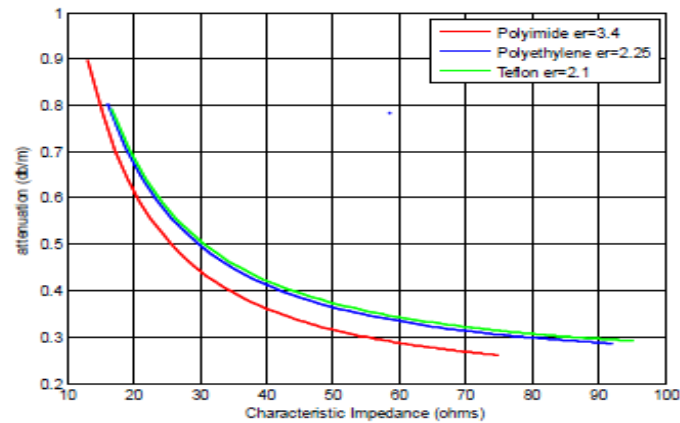


Figure 5. Attenuation of different dielectric

### 3.3. Performance Comparison of the lossy dielectric medium

The coaxial transmission line with many different dielectrics has been tested in Matlab to show the effect of the different dielectric in the coaxial cable. By applying all the equation in the theoretical calculation in the Matlab code to test the performance of the dielectric as shown in the Tables 1-5. The Air has been tested as a dielectric, and it has good performance, but because of mechanical limitations it cannot be practically used. Every dielectric has different properties which means different attenuation constant.

Table 1. relative permittivity of the tested Dielectrics medium

No	Dielectric	$\epsilon_r$
1	Polyimide	3.35
2	polyethylene	2.24
3	Teflon	2.12

The specifications are: 5 MHz propagation wave, Outside diameter of inner conductor ( $d=0.55$ ), Inside diameter of the shield ( $D=1.56$ ), Conductor conductivity  $=5.67e^7$ , and Propagation constant Equation [6] ( $\gamma$ ):

$$\gamma^2 = j\omega\mu(\sigma + j\omega\epsilon) = -\omega^2\mu\epsilon + j\omega\mu\sigma \Rightarrow \gamma = \alpha + j\beta = ((R + j\omega L)(G + j\omega C))^{0.5} \quad (7)$$

Table 2. Matlab results of air as dielectric

Coaxial parameters	Air ( $\epsilon_r = 1$ )
1 Shunt conductance (S/m)	$5.2066e^{-16}$
2 Shunt capacitance (F/m)	$4.72331e^{-11}$
3 Series t inductance (H/m)	$2.4234e^{-07}$
4 Series resistance (ohm/m)	8.9342
5 Gamma $\gamma$	$0.0657+125.664i$
6 Alpha $\alpha$ (NP/m)	0.065718
7 Beta $\beta$ (rad/m)	25.6637
8 Characteristic impedance ( $\Omega$ )	$71.026-0.03714i$

Table 3. Matlab results of polyimide as dielectric

Coaxial parameters	Polyimide ( $\epsilon_r = 3.35$ )
1 Shunt conductance (S/m)	$5.2066e^{-16}$
2 Shunt capacitance (F/m)	$1.5957e^{10}$
3 Series t inductance (H/m)	$2.4234e^{-07}$
4 Series resistance (ohm/m)	8.9342
5 Gamma $\gamma$	$0.1212+231.71i$
6 Alpha $\alpha$ (NP/m)	0.12118
7 Beta $\beta$ (rad/m)	231.7125
8 Characteristic impedance ( $\Omega$ )	$38.52-0.0201i$

Table 4. Matlab results of polyethylene as dielectric

No	Coaxial parameters	Polyethylene ( $\epsilon_r = 2.24$ )
1	Shunt conductance (S/m)	$5.3078e^{-16}$
2	Shunt capacitance (F/m)	$1.0559e^{10}$
3	Series inductance (H/m)	$2.3675e^{-07}$
4	Series resistance (ohm/m)	8.9342
5	Gamma $\gamma$	$0.0986+188.495i$
6	Alpha $\alpha$ (NP/m)	0.098577
7	Beta $\beta$ (rad/m)	188.4956
8	Characteristic impedance ( $\Omega$ )	$47.351-0.02476i$

Table 5. Matlab results of Teflon as dielectric

No	Coaxial parameters	Polyethylene ( $\epsilon_r = 2.24$ )
1	Shunt conductance (S/m)	$\epsilon_r = 2.1$
2	Shunt capacitance (F/m)	$5.3078e^{-16}$
3	Series inductance (H/m)	$9.8555e^{-11}$
4	Series resistance (ohm/m)	$2.3675e^{-07}$
5	Gamma	9.3354
6	Alpha $\alpha$ (Np/m)	$0.0952+182.104i$
7	Beta $\beta$ (rad/m)	0.095234
8	Characteristic impedance ( $\Omega$ )	182.104

#### 4. CONCLUSION

The mathematical model of the coaxial transmission line with the dielectrics mediums is represented based on Matlab software for the Teflon, polyamide and polyethylene. A detailed analysis has been to establish the essence of the dielectrics of the electrical model parameters, characteristic impedance and attenuation.

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